Case review

Fire debris analysis and scene reconstruction

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ABSTRACT

During the summer of 2010 near a little village in the south of Italy, a fire destroyed a piece of brushland without any apparent economic importance. The remains of a fire-setting tool were found at the point of origin of the fire. It was started using a well-planned and methodical approach. The analytical results demonstrated a sophisticated and effective incendiary tool designed to leave little evidence that could identify the offender. The action and the purpose of the arsonist were clear but the basic motivation was unpredictable. The burned area was without any relevant economical interest. It was burnt during the past and has not been used for any cultivation or sheep farming but in the region there was evidence of bushfires that had been lit to stimulate the growth of forest fruits to be harvested for sale.

1. Introduction

Forest or wildfires are often used to describe uncontrolled intense fires that can break out in wooded areas, the causes can be due to many factors, ranging from natural to man-made actions [1]. Wildfires occur throughout the world and are usually cyclical in nature, global warming is suspected to be responsible for an increase in the frequency of forest fires. Forest or wildfires can break out in areas like grassland, woodland, bush and scrubland, they can have seriously damaging effect on the surrounding environment and because of their extensive size and speed, a forest fire can easily spread over vast area [2]. In most cases human activity is responsible for causing forest fires. It is estimated that more than 90% of the forest fires in the world are caused by human activities [3]. One such activity is clearing of land by fire, which sometimes goes out of control and causes a forest fire; often these fires are illegal. Another cause is human negligence, as people can leave behind ignition sources like a camp fire, lit cigarettes, etc. Many times, dry grass is burnt to quicken the growth of new grass, which can also lead to a forest fire. Preventive measures for controlling forest fires usually include activities that can control the outbreak of fire as well as its severity and spread, by maintaining an ecological balance to protect resources. In addition to all of these, people could also play an important role by behaving more responsibly and not leaving behind any fire ignition sources. In Italy only 1 or 2% of forest fires are due to natural causes, so increased surveillance is the most effective weapon for controlling their frequency [3]. However there are people that take advantage or benefit from fire. Arsonists are a varied group of offenders who come from different backgrounds, but the common denominator is a

motivation to burn. The arsonist may increase the fuel load by introducing a flammable material or by adding accelerants such as diesel, gasoline or alcohol, or introduce a heat or ignition source that can be as simple as a match or as complex as chemicals with very low ignition temperatures [4]. To say that the cause of a fire was arson and therefore deliberate, the investigator must have sufficient evidence that at least one of the factors in the fire triangle had been tampered with.

There may be obvious signs of arson such as multiple points of origin or the presence of accelerants. Whatever it is that raises the suspicions of the fire fighters at the scene, it is their observations that initiate an arson investigation. At this point the investigation deviates from the procedures used in a normal criminal investigation. In a normal criminal investigation interviewing witnesses is usually done after the physical evidence is processed [5]. In an investigation of a fire where arson is suspected, the investigator starts the interviewing of witnesses and fire fighters. Eyewitness testimony may provide the most direct link to the arsonist. Physical evidence, such as artefacts and the fire scene itself, provides a more reliable basis for investigation. The interpretation of physical evidence from a fire scene is difficult. An objective investigation strategy can scientifically support defensible and reproducible conclusions [6].

When fire investigators arrive at a fire crime scene, and through physical evidence, determine the location where the fire started, the next question is how the fire started and what materials were used to start the fire. Fire investigators conduct a thorough search of the area around the point of origin for accelerants and igniters. Electrical tools, candles, mosquito coils, electrical timers, oil lamps or cigarettes may be potential ignition sources [7]. The residues found once demonstrated that they were involved in the fire, often are the only actual and direct existing link to the arsonist. Tools for starting a fire vary from the simple to the complex. Matches are perhaps the most common ignition tool. Arsonist many times after lighting fires, tosses the

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matches aside, thinking that the fire will completely destroy them. But even a tiny match can leave trace evidence for investigators. The fire investigators must be able to identify the trace evidence, produce a complete photographic documentation, collect and store the samples in an appropriate manner and entrust them to the scientific crew.

Analytical chemistry plays an important role in the modern forensic science. Many branches have been developed in order to apply the new technologies to fight crime and to help the law [8]. Many skilful laboratories are devoting much time and energy to this field. Crimes by fire, owing to their destructive power, require every time a great deployment of manpower and technologies to clear up the causes and the dynamics. Samples can be analysed by the scientists using several physico-chemical hyphenated techniques, able to provide details on the chemical composition of the collected materials [9,10]. Many laboratories have applied new methods for fire debris, using gas chromatography/mass spectrometry or gas chromatography/mass spectrometry/mass spectrometry [11]. An analytical method and strategy developed also in our laboratory was published in previous papers [12,13]. The aim is to identify the fire accelerants or the components of the hypothetical incendiary tools used. Finally to define the type of fire so that the investigation will restrict to a limited number of suspicious. Only a multi task scientific analysis may allow an accurate crime scene reconstruction.

Here, we will describe the analytical data, the ignition tool reconstruction and its effectiveness in producing a fire like the one started in a southern region of Italy during the summer of 2010.

2. Materials and methods

2.1. Samples

The samples were collected by the National Forestry Corp investigators, from the location where the fire supposedly started. They consisted of:

- A green coloured residue of fused plastic.
- Three wood sticks of about 15 cm length and 1 cm in diameter supposedly cut by a sharp knife. All the tips were sharply cut with five slashes like a pencil point, the end of each stick was cut to the same angle. They were found with the tips pushed into the soil with an angle of about 120° between them and slightly tilted to the outside of the triangle. Around the sticks a lot of ash was found from burned grass. The grass seemed to have been cut, piled into position and held in position against the wind by the sticks.
- A sample of the soil collected just below the plastic residue.

The samples described above were found only a few hours after the fire quench, by following the burn indicators according to the physical evidence method. The method consists in the localization of the point of origin of the fire through the reconstruction of its evolution by analysing its contours and by following the physical indicators left by the fire on the stones, logs, poles, vegetation, etc. [14].

The place where the fire started is shown in Fig. 1 at left. The same Figure, at right, shows the bottom of a green coloured, plastic bottle, accurately cut by a very sharp knife. It was found 29 m from the burnt area and upwind with respect to the location where the other samples were found.

2.2. Accelerant extraction method

Extraction of the analytes was performed using a Solid Phase Micro-Extraction (SPME) syringe introducing the fibre into a 27-ml headspace vial containing an aliquot of the sample debris. The vial was heated to 50 °C for 30 min, allowing the volatile species to be released in the headspace and adsorbed on the PDMS fibre

(100 μm). By introducing the syringe needle into a GC/MS injector, the system automatically desorbed the compounds, carried out a gas chromatographic separation and mass spectrometric detection of the analytes.

Debris samples, suspected to contain wax residues, were treated as following using a procedure proven to be able to identify the chemical components of candles [15]. An aliquot of the suspected sample was heated for 30 min at 100 °C in the presence of hydrochloric acid to obtain the hydrolysis of possible fatty acids. Successively, 500 μl of 2,2-dimethoxy-propane (DMP) was added to the same reaction tube to obtain the corresponding methyl esters. The GC/MS analysis of the liquid phase allowed the identification of most of the components of candle wax such as palmitic and stearic acid methyl esters, as well as the saturated hydrocarbons with carbon chains from 20 to 30 atoms.

2.3. GC/MS instrumentation and analytical conditions

All determinations were performed using a GC/MS system consisting of an HP 6890 Gas Chromatograph coupled with an HP 5973N Quadrupole mass analyser. A chromatographic separation of the analytes was obtained using a HP 5MS capillary column with the following dimensions: length 30 m; internal diameter 0.25 mm and film thickness 0.25 μm. The column, with a constant helium flow of 0.7 ml/min, was submitted to the following temperature programme: 45 °C×3 min − 10 °C/min − 250 °C×15 min. The injector temperature was 250 °C. All injections were performed under splitless conditions for 0.7 min. The mass spectrometer was in SCAN acquisition mode in the mass range from 50 to 300 Da, with a scan rate of 5.56 scan/s mode to detect the ions produced by electron impact ionisation (70 eV). The ion source temperature was 230 °C. The 2,2-dimethoxy-propane derivatives were analysed by the same GC/MS instrument using a specific column temperature programme, starting from 100 °C×1 min and by means of a ramp of 9 °C/min to a final temperature of 270 °C, while the coupled quadrupole mass analyser recorded the ion current in the range 50–450 Da.

2.4. μFT-IR analyses

All the IR measurements were performed by using an FT-IR Thermo Scientific Nicolet iN10 microscope, equipped with a MCT/A detector cooled with liquid nitrogen and Slide-On Micro-Tip ATR using a germanium crystal (refraction index = 4).

The IR data were collected in the spectral range 4000–675 cm^{-1}, accumulating 64 scans in 12 s at a resolution of 8 cm^{-1}.

3. Analytical results and discussion

3.1. GC/MS analyses

A sample of soil collected beneath the plastic residue was analysed using the SPME/GC/MS technique. The ion current profiles at m/z 55 and m/z 57 are reported in Fig. 2. Excluding the peaks at 18.5 and 21.0 min, which are an artefact of the technique and diisobutyl phthalate, the extract chromatograms show two Gaussian profiles with maxima at 12.4 and 22.1 min. The first one, together with the alkane hydrocarbons represented by the ion current at m/z 57 showed a higher concentration of alkene hydrocarbons represented by the ion current at m/z 55. The product distribution deriving from the thermal degradation of polyalkenes has been studied by several authors [16]. Gas chromatographic analysis with mass spectrometric detection showed that polyethylene degradation products display distinct gas chromatographic patterns of a series triplets composed of the aliphatic hydrocarbons having the same carbon atom number in a broad range of carbon atoms eluted on the non-polar stationary phase in the order alkadiene, alk-1-ene and n-alkane [16].

Fig. 1. Left: The layout of the site where the fire started. Right: The bottom of a plastic bottle found at 29 m out-side the burned area.

The second maximum of the hydrocarbon profile in Fig. 2 shows only alkane hydrocarbons with chain length between C18 and C24 being present. The most popular type of candle wax used today is paraffin wax. The chemical composition of paraffin wax is commonly referred as to as $C_{25}H_{52}$. However, the actual number of carbon atoms can typically range from 22 to 27. A wax molecule is known to be a long hydrocarbon with a general chemical formula of C_nH_{2n+2}, with n being a varying number of carbon atoms (C22–C27). Although the chemical composition of the wax is always carbon and hydrogen, the actual number of atoms will vary based on the exact origin of the wax.

The same soil sample treated at high temperature with hydrochloric acid and DMP, as described in the Materials and methods section, on GC/MS analysis gave the results shown in Fig. 3. This figure shows the total ion current, the chromatographic peaks at 14.8 and 16.9 min were identified by the mass spectral data bank and by the use of certified standards, as methyl esters of palmitic and stearic acids. The other peaks were attributed to alkane hydrocarbons. The alkane profile in Fig. 3 is quite different from the profile shown in Fig. 2 because of the different sampling and injection method applied. Paraffin is by far the most frequently used candle wax on a worldwide basis today. However, its lower melting point between 47 and 64 °C caused problems. Stearic acid, actually a mix of stearic acid and palmitic acid, is a long-chain fatty acid often used in candle-making. Its primary property is to raise the melting point of the wax mixture, making the resulting candle harder and more durable. The chemical composition of the analysed wax included both components, paraffins and fatty acid esters. The overall analysis

of GC/MS chromatograms has ruled out the presence of the most common fire accelerants in the debris.

3.2. μFT-IR analyses

The green coloured residue of fused plastic was analysed by stereo optical microscopy to identify any superficial inhomogeneity or contamination. Fig. 4 (left) shows a white plastic material fused together with the green material. The white material was a flat strip fused on the surface and it was present around the green residue. To understand the nature and the distribution of the white material a section of the sample was cut and submitted to μ-FT-IR analysis, Fig. 4 (right). The IR analytical spectra are shown in Fig. 4 (right). They have been obtained by ATR analysis of 18 points along a line through the white and green materials.

Four sharp peaks dominate the spectrum in the white area. The match between the obtained spectra and the IR data bank of polyethylene (PE) was higher than 96%. A match of 89% was found when comparing the spectra of the green area with the IR data bank spectrum of polyethylene terephthalate (PET).

Infrared spectroscopy is the most direct means for the identification of polymers. Through the use of the reference infrared spectra, an unknown polymer can be quickly identified. When additional peaks are present in the infrared spectrum, they may be from an additional polymer. The white PE material fused on the surface of the PET green residue may be attributed to the neck ring of an opened bottle without the cap which is typically made of PE plastic. The most
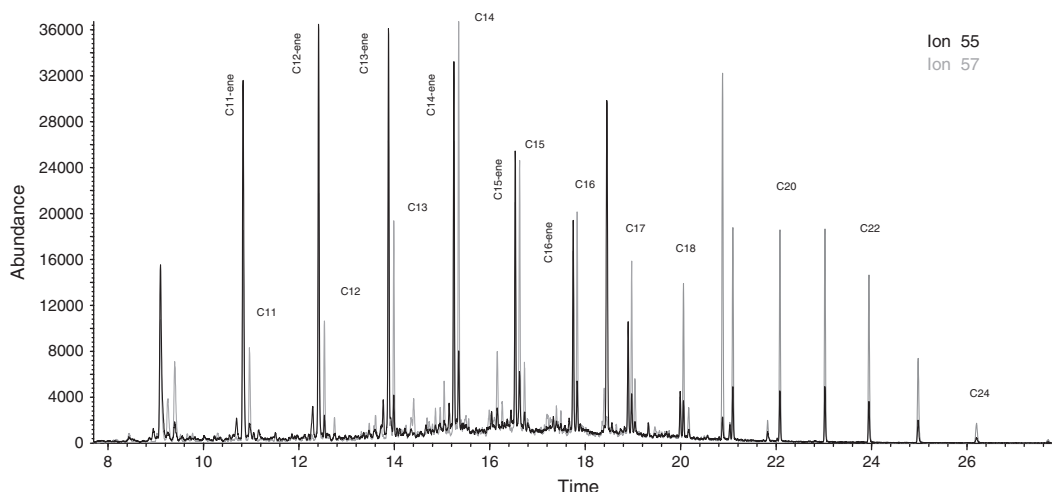

Fig. 2. The ion current profiles at m/z 55 and m/z 57 of the soil sample collected below the plastic residue analysed by SPME/GC/MS technique.
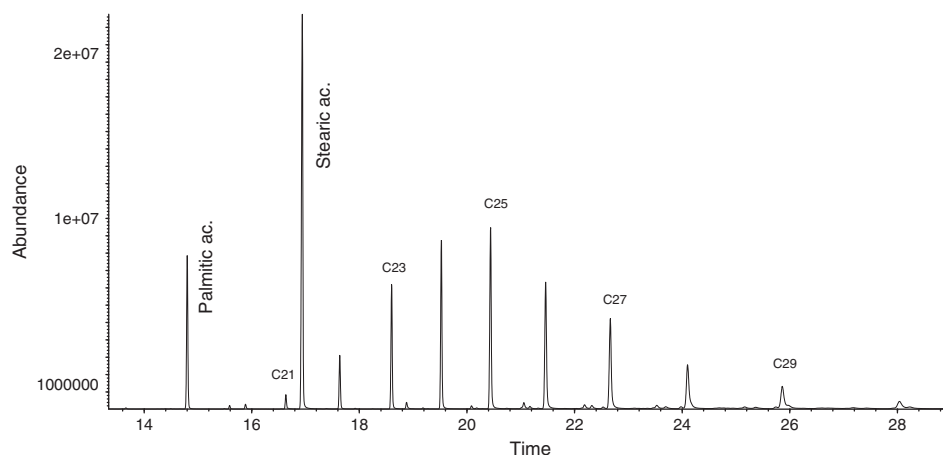
Fig. 3. Total ion current of the GC/MS analysis of soil sample treated at high temperature with hydrochloric acid and DMP.

important result was that the white plastic identified the neck of a fused bottle used by the arsonist without the cap.

3.3. Reconstruction of the incendiary tool and test of its effectiveness

The discovery of the three wood sticks, their arrangement at the fire starting point, the presence of the cut bottom of a green PET bottle close to the burned area, together with the GC/MS and μFT-IR analyses have allowed us to reconstruct the hypothetical tool used. A half litre PET bottle without the cap was cut just above the bottom. A standard house candle of 2.0 cm diameter and 15.0 cm height was inserted with the end into the neck of the cut bottle. The candle bottom fitted exactly inside the neck and the entire candle was fitted inside the cut bottle. Three sticks were placed on a heap of dry vegetable matter, to reproduce the layout seen in Fig. 1. The bottle containing the candle was placed in the middle, ensuring that it was perfectly upright, to avoid contact of the flame with the bottle wall, and in a position that meant that there was enough fuel material below the bottle neck, as shown in Fig. 5 (left). After setting, the tool was lit with a match and the evolution of the tool was followed by recording each phase. The molten wax dripped from the burning tip of the candle and accumulated at the closed neck of the bottle to make a small wax lake. After about 5 h, once the candle was almost completely consumed and after the almost complete consumption of the accumulated wax, the last piece of the still burning candle dropped through the bottle neck and landed on the vegetable fuel. The dry material quickly started to burn and the complete vegetable heap was completely burnt within a few minutes. Fig. 5 (right)

shows the remains at the end of fire test. The test was repeated twice, obtaining the same results confirming that a similar tool may have been used to start the forest fire. The tool had been accurately designed and was probably tested before the fire.

4. Conclusion

The analytical results on the debris have clearly identified the components of the tool. The results of gas chromatographic and μ-FTIR on the plastic residues have also clarified the arrangement of the tool components. Furthermore, the uncommon blend of wax identified, may provide more clue for further investigations. The fire scene reconstruction and the fire setting tool used, suggest that the arsonist's purpose was to burn a small brush glade not far from a country house and the village, from these points it was almost impossible not to see the fire smoke. The setting point and the time chosen are more clues justifying the purpose that only a small fire was required. The country house and the village were up-wind of the fire. The fire was started just before lunch time and many people were on the street. The alert was immediate and the fire was extinguished in 2 h. The actions and the purpose of the arsonist were clear but not the motivations. Probably he was induced by profit, but the burned area was without any relevant economical interest. It was burnt during the past and has not been used for any cultivation or sheep farming but in the region there was evidence of bushfires that had been lit to stimulate the growth of forest fruits to be harvested for sale.
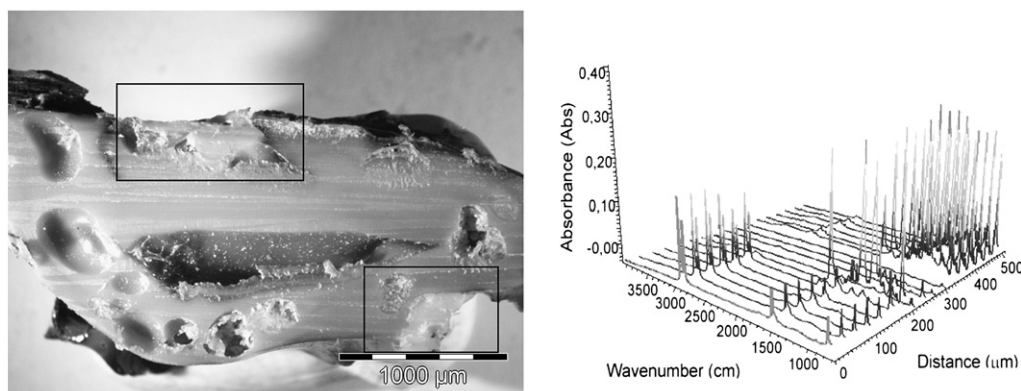

Fig. 4. Left: The microscopy image of a section of the plastic residue. The white material in the squares was a flat plastic strip fused on the green surface. Right: 3D representation of the μ-FT-IR analysis obtained by ATR on 18 points along a line through the white and green materials.

Fig. 5. Left: Layout of the reconstructed incendiary tool. Right: The end of the laboratory effectiveness test.

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